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THE GEOLOGIC RECORD OF CALIFORNIA

JAMES PERRIN SMITH
Stanford University, Cal.

The geologic record of California is exceedingly complete for a single geographic region, because of the two ancient and persistent seas that covered some portion of its surface during each geologic period. These seas were the Pacific Ocean and the Great Basin Sea.

The geologic history of California is given below chiefly in the form of tables, for the sake of brevity, and without a discussion of the faunas and floras of the various formations, since that would extend the paper beyond the size intended. Such a discussion is reserved for a later paper.

The tables here given have been based on a critical study of all the papers on the stratigraphy of California, and on the writer's experience in this field for a period of seventeen years, of which a large part has been spent in field study.

Great Basin Sea.—The older portion of the geologic record, from the Cambrian to the top of the Middle Jurassic, has been preserved chiefly in the sediments of the Great Basin Sea, while during those ages that part of California which was afterward covered by the Pacific Ocean was either above water, or has had its sediments so much metamorphosed that their age is not positively determinable.

The Great Basin Sea of Paleozoic and early Mesozoic time covered approximately the area of the Great Basin of the present age, sometimes more, and sometimes less, dwindling away gradually from the noble expanse of the Carboniferous Sea to the shrunken remnant in early Mesozoic time. This basin at all times was directly connected with the Pacific Ocean, by a broad passage to the northwest; and during a part of the Paleozoic, especially during the period of the Coal Measures, it was joined to the Mississippian Sea. At all other times it was exclusively western, and the marine Triassic and Jurassic history of the United States is its peculiar property. It has played

ARCHAEAN	PALEOZOIC										
	Cambrian		Silurian		Devonian			Carboniferous			
	Lower			Upper		Middle		Mississippian		Coal Measures	
				Niagara							
	Silver Peak			Grizzly		Sacramento		Bragdon	McCloud		
				Mont-gomery		Kennett			Baird	McCloud Limestone	Nosoni
Schists and gneisses of the Sierra Nevada	Limestones of White Mountains with Olenellus, and banks of Archaeocyathus			Limestone of Plumas County, with Niagara fauna		Limestones of Kennett, with coral reefs, Favosites canadensis		Bragdon shales of Trinity County	Black siliceous shales of McCloud River, with Productus giganteus, P. burlingtonensis, Orthis michelini	Gray limestones of McCloud River with Fusulina robusta, F. cylindrica, Clisiophyllum gabbi	Sandstones and tuffs of Shasta and Plumas counties with Fusulina elongata

GEOLOGIC COLUMN OF CALIFORNIA

STANDARD MARINE SECTION

		MESOZOIC									
OUS		TRIASSIC						JURASSIC			
ures	Permian	Lower	Middle		Upper			Lower		Middle	
								Lias		Oölite	
		Inyo						Plumas			
Nosoni	Wildwood	Meekoceras Beds	Parapopanoceras Beds	Pitt	Hosselkus		Brock	Hardgrave			
Sandstones and tuffs of Shasta and Plumas counties with Fusulina elongata	Limestones of Trinity County with Guadalupian fauna, Stacheoceras, etc.	Gray limestones of Inyo Mountains with Meekoceras gracilitatis, Pseudosageceras intermontanum, and Ussuria compressa	Black limestone of Inyo Mountains with Parapopanoceras, Hungarites, and Ptychites	Black shales of Pitt River, with Ceratites, Anolcites, and Arcestes	Shales of Brock Mountain with Halobia rugosa	Limestones of Shasta County with reef corals, Tropites subbullatus, and Halobia superba	Shales with Pseudomonotis subcircularis	Arietites beds of Inyo County and Nevada	Sandstones of Taylorsville, Big Bend, with Pecten acutiplicatus	Mormon sandstone with Oölite fauna	[illegible] and sandstone of Plumas County, with reef corals
										Oroville Flo	
										Monte de Oro slates of Oroville, with lower Oölite flora, associated with marine Jurassic forms	

GEOLOGIC COLUMN OF CALIFORNIA

STANDARD MARINE SECTION

	MESOZOIC									
	TRIASSIC						JURASSIC			
Permian	Lower	Middle		Upper			Lower		Middle	
							Lias		Oölite	
	Inyo						Plumas			
Wildwood	Meekoceras Beds	Parapopanoceras Beds	Pitt	Hosselkus		Brock	Hardgrave			
Limestones of Trinity County with Guadalupian fauna, Stacheoceras, etc.	Gray limestones of Inyo Mountains with Meekoceras gracilitatis, Pseudosageceras intermontanum, and Ussuria compressa	Black limestone of Inyo Mountains with Parapopanoceras, Hungarites, and Ptychites	Black shales of Pitt River, with Ceratites, Anolcites, and Arcestes	Shales of Brock Mountain with Halobia rugosa	Limestones of Shasta County with reef corals, Tropites subbullatus, and Halobia superba	Shales with Pseudomonotis subcircularis	Arietites beds of Inyo County and Nevada	Sandstones of Taylorsville, Big Bend, with Pecten acutiplicatus	Mormon sandstone with Oölite fauna	[illegible] and sandstone of Plumas County, with reef corals
									Oroville Flo	
									Monte de Oro slates of Oroville, with lower Oölite flora, associated with marine Jurassic forms	

LAND EQUIVALENT

		CRETACEOUS					TERTI				
Upper		Lower			Upper		Eocene		Oligocene		
t-dge	Portland	Neocomian		Gault	Cenomanian Danian ?		Midway	Claiborne		Lower	
rous Slates		Shasta			Chico						
iposa	Colfax	Knoxville		Horsetown			Martinez	Tejon	Astorian	Vaqueros	Monte
Maripo tes of the Gold Belt with and	Tuffs and shales of the Gold Belt with Perisphinctes colfaxi	Lower Knoxville shales with Phylloceras knoxvillense and Aucella piochii	Upper Knoxville shales of Coast Ranges with Aucella crassicollis	Horsetown shales of Sacramento Valley with Desmoceras hoffmanni, Phylloceras onoënse, Lytoceras batesi	Lower Chico beds with Schloenbachia, Placenticeras, Phylloceras ramosum	Upper Chico sandstones with Schloenbachia chicoensis and Pachydiscus newberryanus	Sandstones of Martinez with Pholadomya nasuta	Sandstones of Ft. Tejon, Martinez, and Merced Falls with Venericardia planicosta	San Lorenzo Sandstones and shales of Santa Cruz County	Sandstones of Monterey and San Luis Obispo counties, with Turritella inezana and Mytilus mathewsoni	Monterey Shales with Pecten discus and Pecten peckhami
Oregon Flora		Shasta Flora			Chico Flora			Auriferous Grave			
								Ione Formation			
	Flora of southern Oregon supposed to be Jurassic, but possibly associated with marine Knoxville forms	Shasta flora associated with Knoxville species		Shasta flora associated with Horsetown species				Coal beds of Mt. Diablo region with subtropical flora			

	CENOZOIC													
	Tertiary									Quaternary				System
	Eocene		Oligocene	Miocene				Pliocene		Pleistocene				
	Midway	Claiborne		Lower	Middle		Upper							
														Series
	Martinez	Tejon	Astorian	Vaqueros	Monterey	Santa Margarita	San Pablo	San Diego	Merced		San Pedro			Formation
Upper Chico sandstones with Schloen-	Sandstones of Martinez with Pholadomya nasuta	Sandstones of Ft. Tejon, Martinez, and Merced Falls with Venericardia planicosta	San Lorenzo Sandstones and shales of Santa Cruz County	Sandstones of Monterey and San Luis Obispo counties, with Turritella inezana and Mytilus mathewsoni	Monterey Shales with Pecten discus and Pecten peckhami	Sandstones of Salinas Valley, with Pecten estrellanus, Ostrea titan, and Tamiosoma gregaria	Sandstones of San Pablo Bay and the Coalinga region, with Pecten pabloensis and Pecten oweni	Purisima Sandstones of San Diego and Half Moon Bay, with Pecten healeyi	Sandstones of Lake Merced with Cardium meekanum and Scutella interlineata		Deadman Island beds	Los Cerritos beds		
		Auriferous Gravels						Paso Robles						
		Ione Formation												
		Coal beds of Mt. Diablo region with subtropical flora					Upper flora of Mt. Diablo region	Tulare lake beds	Santa Clara lake beds	Glacial beds			Terrace formations	

very much the same part in the geologic history of North America as the ancient Mediterranean or Tethys did in the history of Europe, though on a much smaller scale, since it was epicontinental, and not intercontinental. The Cambrian, Silurian, and Devonian sediments of California are mere fragments of little area and thickness, representing only a small part of the entire time of those ages. The Carboniferous, however, is fairly complete, all three major divisions being fully represented by marine faunas. The Triassic period is well represented; the Lower Triassic is nearly as good as the standard American section of Idaho; the Middle Triassic has both of the greater divisions, although the main portion is not nearly so complete as the standard section of the West Humboldt Range in Nevada. The Upper Triassic of California is the standard for this epoch in America, and compares very favorably with the rest of the world in the richness of its faunas, and the completeness of the record. The Jurassic section of the Great Basin Sea is the most complete in the United States, having portions of each stage from Lias to Kelloway, inclusive; but it is fragmentary, the faunas being poorly preserved and scanty. It is not comparable with the Jurassic record of Alaska and British Columbia, and nowhere approaching that of South America. With this epoch the marine column of the Great Basin ends abruptly, as the sea was obliterated at the beginning of the Cordilleran revolution.

Pacific record.—The marine record of California from the bottom of the Upper Jurassic through the Quaternary was kept exclusively by the Pacific Ocean. This was divided between two provinces, or areas of sedimentation, the Sierra Nevada, and the Coast Ranges, but the distribution was not balanced. The Pacific province is one of the great geosynclines, with sediments approximating seventy thousand feet in thickness, and undergoing subsidence more or less continuously, though spasmodically, from the Triassic onward, interrupted by great periods of orogenic activity. This is a part of that grand structural feature of the continent of which the Great Valley, the Gulf of California, the Willamette Valley, and Puget Sound are mere remnants.

The recognizable Paleozoic and early Mesozoic sediments are confined to the Sierra Nevada, while the Cretaceous and Tertiary

GEOLOGIC RECORD OF THE GREAT BASIN SEA IN CALIFORNIA

Cenozoic	Quaternary		Lahontan lake beds
	Tertiary		Miocene, Truckee, lake beds
			Eocene, Esmeralda, lake beds
Mesozoic	Jurassic		Cordilleran revolution, uplift and metamorphism of Sierra Nevada and obliteration of the Great Basin Sea
		Middle	Hinchman tuff and sandstone of Plumas County, with Kelloway fauna, and reef-building corals
			Mormon sandstone and Thompson limestone of Plumas County with lower Oölite fauna
		Lower	Hardgrave sandstone of Plumas County, with Upper Liassic fauna
			Arietites limestones of Inyo County, California, and West Humboldt Range, Nevada
	Triassic	Upper	Pseudomonotis shales of Shasta and Plumas counties
			Hosselkus limestone of Shasta County, with coral reefs. *Tropites subbullatus* fauna.
		Middle	Pitt shales of Shasta. Star Peak limestone of West Humboldt Range, Nevada
			Black limestone of Inyo Range, with Middle Triassic fauna
		Lower	Gray limestone of Inyo Range, with Meekoceras fauna
Paleozoic	Carboniferous	Upper	Wildwood limestone of Trinity County, with Permian fauna
			Nosoni tuffs and shales of Shasta County, with fauna transitional to Permian
		Middle	McCloud limestone of Shasta County, with Coal Measures fauna, and coral reefs
		Lower	Baird shales of Shasta, with Asiatic Subcarboniferous fauna
			Bragdon shales of Trinity County, without definite fauna
	Devonian	Middle	Kennett limestones of Shasta County, with coral reefs, *Favosites, Diphyphyllum,* etc.
	Silurian	Niagara	Montgomery limestone of Plumas County, with reef-building corals
	Cambrian	Lower	Olenellus limestone of Inyo County, with reefs of Archaeocyathus
Archaean			Pre-Cambrian schists of Inyo County

strata are most complete in the Coast Ranges. The Sierran record is fragmentary, the formations being incomplete, separated by great unconformities, including great masses of tuffs and igneous rocks, and showing evidence of important recurring orogenic and volcanic activity.

The Coast Range province, too, showed this same phenomenon in its Paleozoic and early Mesozoic sediments, but from the bottom of the Cretaceous to the middle of the Miocene conditions were more uniform, indicating moderately quiet advance and retreat of the sea, with minor unconformities, smaller masses of igneous intrusives, and outpourings of surface lavas. The Coast Range revolution, about the middle of the Miocene epoch, broke the monotony of this history, and for a time there was much mountain-making activity. Minor outpourings of lava occurred along the coast, while farther to the northeast the Columbian lava flood overwhelmed an area of about two hundred thousand square miles, and the rejuvenation of the Sierra Nevada was beginning.

The Cretaceous section of the Coast Ranges is more complete than that of any other single province in America. It lacks only the uppermost portion, and shows a variety of conditions not seen anywhere else, from the boreal faunas of the Knoxville to the tropical faunas of the Horsetown and Chico epochs, with fossil floras interbedded in every formation.

The Tertiary marine section of the Coast Ranges is not only the most complete in America, but also more complete than that of any other single geographic region in the world. Every minor division is fully represented by marine faunas, and most of them have fresh-water beds intercalated, with fossil plants and freshwater animals.

The Quaternary marine section of the Coast Ranges is the most complete that has been described, for this is almost the only known region where there has been much post-Quaternary orogenic activity. In nearly all other regions the Quaternary sediments are still buried under the oceans in which they were deposited.

ROCK-FORMING AGENCIES OF CALIFORNIA

Igneous rocks.—A large part of the surface of the state, a little less than one-half, is made up of igneous rocks. Of these the most important group consists of deep-seated granitic rocks, granites, grano-diorites, diorites, and gabbros, compounds of feldspars and ferro-magnesian minerals, such as hornblendes, pyroxenes, and mica. The greatest of these batholites is the great igneous mass of the Sierra Nevada, making up the bulk of that mountain chain. Smaller batholites of similar character are in the Sierra Madre Range, the White Mountain Range, the Klamath Mountains, and in the Santa Lucia Mountains.

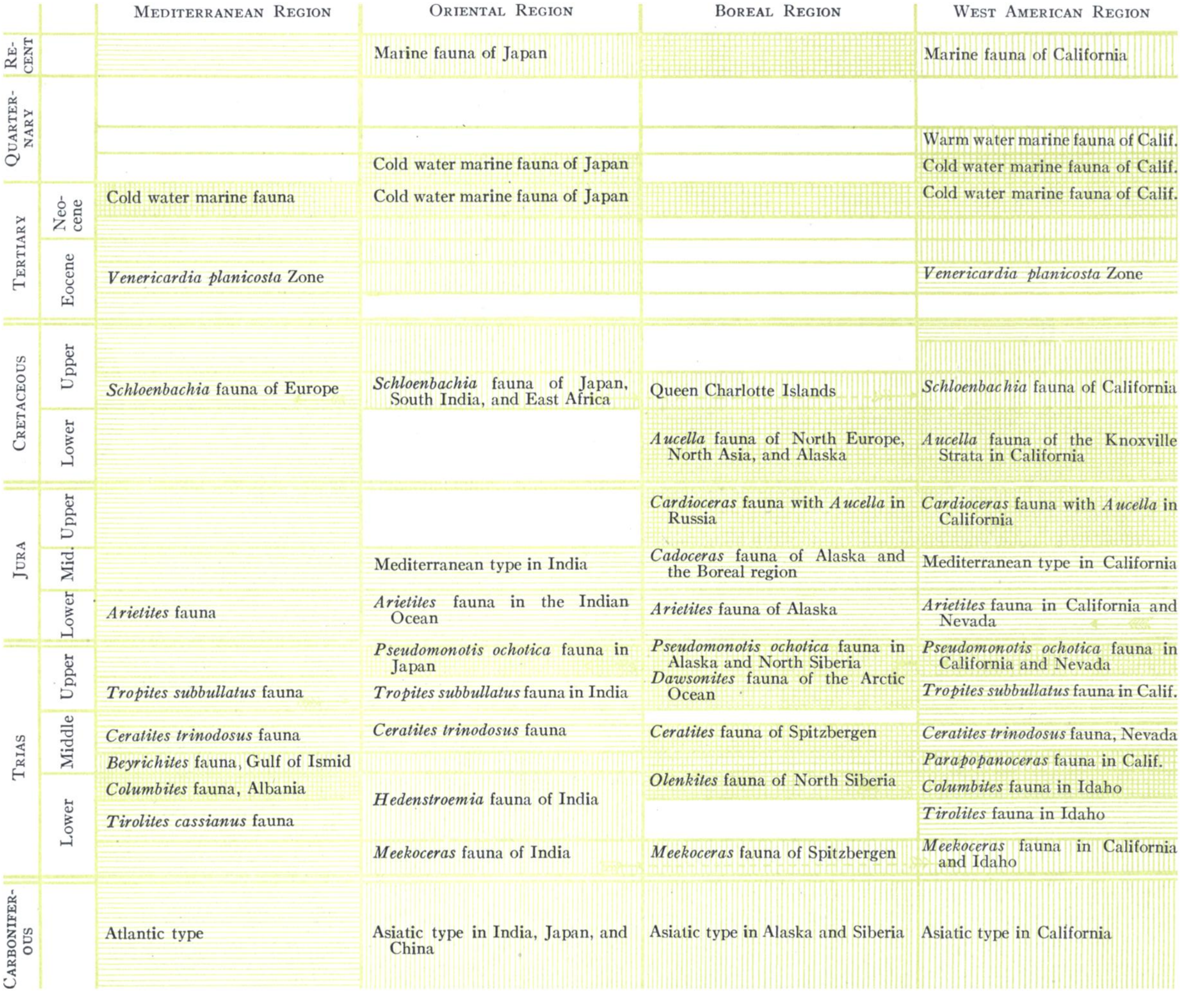
Associated with the deep-seated granitic rocks in nearly all these regions there are numerous dyke-rocks, similar in chemical nature to the parent masses, but showing only a small surface area.

A second group is composed of basic intrusives, chiefly peridotites, now largely changed to serpentine, rich in olivine and other ferro-magnesian minerals. These cover great stretches in the Coast Ranges, where they are largely of Franciscan age, older than the Cretaceous; they also form less extensive masses in the Sierra Nevada.

A third group is composed of lavas, mostly andesites and basalts, surface flows from volcanoes. These are chiefly of Tertiary age, Middle Miocene, and, together with the less important rhyolite flows, they cover broad areas in northeastern California, and smaller patches in all the other mountain regions of the state. The flows in northeastern California are a part of the Columbian field, and doubtless came from fissure-eruptions. The others came from ordinary volcanoes, though in most cases the volcanic cones are long since destroyed. Mt. Shasta and Lassen Peak are the two grandest volcanoes of the state, the southern extension of the Cascade Range, still preserving their ancient form and some feeble remnants of their old-time activity.

Inorganic sediments.—The greater part of the surface of California, a little more than half, is made up of sediments. These are of two groups, (1) inorganic, and (2) organic.

The inorganic sediments are far greater in thickness and areal extent, sandstones and shales, derived from the decay of crystalline rocks. The quartz and undecomposed feldspars furnished the sand grains, and the decomposed feldspars furnished the clay for the shales. The sandstones of California are remarkable for the large quantity they contain of undecomposed fragments of minerals derived



		MEDITERRANEAN REGION	ORIENTAL REGION	BOREAL REGION	WEST AMERICAN REGION
RE-CENT			Marine fauna of Japan		Marine fauna of California
QUARTER-NARY					Warm water marine fauna of Calif.
			Cold water marine fauna of Japan		Cold water marine fauna of Calif.
TERTIARY	Neo-cene	Cold water marine fauna	Cold water marine fauna of Japan		Cold water marine fauna of Calif.
	Eocene	*Venericardia planicosta* Zone			*Venericardia planicosta* Zone
CRETACEOUS	Upper	*Schloenbachia* fauna of Europe	*Schloenbachia* fauna of Japan, South India, and East Africa	Queen Charlotte Islands	*Schloenbachia* fauna of California
	Lower			*Aucella* fauna of North Europe, North Asia, and Alaska	*Aucella* fauna of the Knoxville Strata in California
JURA	Upper			*Cardioceras* fauna with *Aucella* in Russia	*Cardioceras* fauna with *Aucella* in California
	Mid.		Mediterranean type in India	*Cadoceras* fauna of Alaska and the Boreal region	Mediterranean type in California
	Lower	*Arietites* fauna	*Arietites* fauna in the Indian Ocean	*Arietites* fauna of Alaska	*Arietites* fauna in California and Nevada
TRIAS	Upper		*Pseudomonotis ochotica* fauna in Japan	*Pseudomonotis ochotica* fauna in Alaska and North Siberia	*Pseudomonotis ochotica* fauna in California and Nevada
		Tropites subbullatus fauna	*Tropites subbullatus* fauna in India	*Dawsonites* fauna of the Arctic Ocean	*Tropites subbullatus* fauna in Calif.
	Middle	*Ceratites trinodosus* fauna	*Ceratites trinodosus* fauna	*Ceratites* fauna of Spitzbergen	*Ceratites trinodosus* fauna, Nevada
		Beyrichites fauna, Gulf of Ismid			*Parapopanoceras* fauna in Calif.
	Lower	*Columbites* fauna, Albania	*Hedenstroemia* fauna of India	*Olenkites* fauna of North Siberia	*Columbites* fauna in Idaho
		Tirolites cassianus fauna			*Tirolites* fauna in Idaho
			Meekoceras fauna of India	*Meekoceras* fauna of Spitzbergen	*Meekoceras* fauna in California and Idaho
CARBONIFER-OUS		Atlantic type	Asiatic type in India, Japan, and China	Asiatic type in Alaska and Siberia	Asiatic type in California

GEOGRAPHIC RELATIONS OF WESTERN AMERICAN FOSSIL FAUNAS

ARCHAEAN ?	PALEOZOIC	MESOZOIC				
	Paleozoic	Triassic	Jurassic		Cre	
	Santa Lucia		Franciscan		Knoxville	
	Santa Lucia limestone gneisses and granites, without definite fossils	Wanting ?	Cherts, limestones, shales, and schists without definite fossils and with great intrusions of basic igneous rocks, all pre-Cretaceous, and in part possibly even Triassic in age	Cordilleran revolution	Knoxville shales and conglomerates	
				Oregon flora	Shas flor	
				Plant beds of northern California and southern Oregon, supposed to be of Jurassic age	sociated with Knoxville and Horsetown marine species	

Archaean ?	Silurian	Carboniferous	Triassic of the Gold Belt		Mariposa	Colfax		
	Grizzly	Calaveras formation		Oroville flora				
Older gneisses of Sierra Nevada	Montgomery limestone of Plumas County, with Niagara fauna	Limestones and quartzites of the Sierra Nevada, with Carboniferous fossils	Sailor Canyon shales Genessee Valley limestone and shales	Oroville flora, with cycads of Middle Jurassic age	Mariposa shales, with marine fossils of Upper Jurassic age	Colfax shales and altered tuffs, and igneous rocks. Marine record almost destroyed	Cordilleran revolution	Erosion period. Record wanting

ACIFIC RECORD

			Cenozoic														
Cretaceous			Tertiary											Quaternary			
oxville	Horsetown	Chico	Eocene		Oligocene	Miocene						Pliocene					
Knoxville shales and conglomerates	Horsetown sandstones and shales of Shasta and Tehama counties	Chico sandstones	Martinez sandstones	Tejon sandstones	San Lorenzo sandstones and shales	Vaqueros sandstones	Temblor sandstone	Monterey shale	Coast Range revolution	Santa Margarita sandstones	San Pablo and Etchegoin sandstones	San Diego and Purisima sandstones	Merced sandstones	Canyon-cutting epoch	San Pedro sandstones	Terrace	Coast Ranges
Shasta flora		Chico flora															
Plant beds of northern California and southern Oregon, associated with Knoxville and Horsetown marine species		Plant beds in northern California associated with Chico marine species		Lake beds of Corral Hollow, with Eocene plants						Lake beds of Tesla, with Upper Miocene leaves		Tulare lake beds	Santa Clara lake beds				
		Chico	Auriferous Gravels														Sierra Nevada
				Ione formation													
Erosion period. Record wanting		Chico sandstones of Butte County, with marine fossils	Wanting	Mohawk lake beds, and coal beds of Ione. Marine sandstones of Merced Falls			Ocoya Creek sandstones, with marine fossils	Chief volcanic period		Post-volcanic gravels, with Upper Miocene leaves				Glacial beds		Terrace gravels	

FIC RECORD

			Cenozoic														
Cretaceous			Tertiary											Quaternary			
le	Horse-town	Chico	Eocene		Oligo-cene	Miocene						Pliocene					
	Horsetown sandstones and shales of Shasta and Tehama counties	Chico sandstones	Martinez sandstones	Tejon sandstones	San Lorenzo sandstones and shales	Vaqueros sandstones	Temblor sandstone	Monterey shale	Coast Range revolution	Santa Margarita sandstones	San Pablo and Etchegoin sandstones	San Diego and Purisima sandstones	Merced sandstones	Canyon-cutting epoch	San Pedro sandstones	Terrace	Coast Ranges
Shasta flora		Chico flora															
Plant beds of northern California and southern Oregon, associated with Knoxville and Horsetown marine species		Plant beds in northern California associated with Chico marine species		Lake beds of Corral Hollow, with Eocene plants						Lake beds of Tesla, with Upper Miocene leaves		Tulare lake beds	Santa Clara lake beds				
		Chico	Auriferous Gravels														
				Ione formation													
Erosion period. Record wanting		Chico sandstones of Butte County, with marine fossils	Wanting	Mohawk lake beds, and coal beds of Ione. Marine sandstones of Merced Falls			Ocoya Creek sandstones, with marine fossils	Chief volcanic period		Post-volcanic gravels, with Upper Miocene leaves				Glacial beds		Terrace gravels	Sierra Nevada

from the igneous rocks, so that they more often arkose and greywacke than true sandstones.

Thick beds of aluminous shales, now largely changed to slates, are found in the Carboniferous and Jurassic rocks of the Sierra Nevada, and to a less extent in the Franciscan formation of the Coast Ranges. The Auriferous Slates also form the surface rocks of considerable areas in the Klamath Mountains.

Less altered shales are extensively developed in all the later formations of the state, from the Lower Cretaceous upward, although not on such a grand scale as in the older periods.

The greatest individual mass of sediments in California is formed by the Quaternary and Pliocene fluviatile deposits of the Great Valley. This mass is about four hundred miles long by fifty in width, and is several thousand feet thick in the middle, thinning out toward the edges, surpassing the enormous mass of Tertiary sediments. These valley deposits have been bored to a depth of three thousand feet, without reaching bed-rock, but there are too few deep borings for an estimate of the average thickness to be possible.

A second great mass of clastic sediments is seen in the Tertiary sandstones of the Coast Ranges, which extend nearly the entire length of the state, and have a total thickness of about fifteen thousand feet, although not all of this at any one place. A remnant of this series is seen along the western flank of the Sierra Nevada in the marine and brackish-water Ione formation, and the upland equivalent is seen in the Auriferous Gravels.

A third great mass of sandstones is found in the Cretaceous of the Coast Ranges, where a thickness of about thirty thousand feet was deposited. This thickness surpasses by far that of the Tertiary sandstones, but the areal extent is much less. These, too, overlapped on the foot of the Sierra Nevada.

Smaller masses of sandstone, now largely changed to quartzite, are seen in the early Mesozoic and Paleozoic formations of the Sierra Nevada and Coast Ranges, but nowhere forming extensive surface areas.

On the western flank of the Sierra Nevada, throughout the Gold Belt, there are in the late Paleozoic and in the late Jurassic thick beds of tuffs, or volcanic ash, now altered to greenstone schists.

These in places have a thickness of several thousand feet, but do not form considerable areas of the surface rocks.

Organic sediments.—These do not make much of a figure on the areal map of the state, but play a large part in its economic history. They are limestones, siliceous shales, and plant accumulations in the form of coal or lignite.

The limestones are entirely of organic origin, with the exception of some smaller occurrences of late spring deposits, or calcareous tufa, which, however, are large enough to be used in the manufacture of cement.

The great masses of limestone are confined to the Paleozoic and early Mesozoic, though as late as the middle of the Jurassic period there are some large beds of limestone. They are formed of ground-up shells, corals, and foraminifers that lived in quiet, clear waters, but are now largely crystalline, most of the evidence of their organic origin having been destroyed in the great mountain-making revolutions that have passed over them. The formation of limestone on a large scale in California was confined to epochs that we know from other evidence were warm, and also to epochs when sheltered, clear seas covered portions of the state. In such seas corals and foraminifers abounded, and the evidence of their rock-forming activity is still visible in the coral reefs of the Paleozoic and Triassic, and the Fusulina limestone of the Carboniferous.

From the middle of the Mesozoic up to the Eocene it was still warm enough at times for reef-building corals, and foraminifers to have flourished in the seas of California; but the warm epoch of the Middle Jurassic was a time of igneous activity, and during the Cretaceous there was too much sand and mud poured into the water for these organisms to find a favorable habitat.

Limestones, at least in part formed by corals, have a thickness of several thousand feet in the Cambrian of Inyo County, but the areal extent is unknown. The Devonian of Shasta and Siskiyou counties shows coral reef rock to the thickness of several hundreds of feet, of small area. These are all surpassed in the great masses of Carboniferous limestone, of the White Mountains, the western flank of the Sierra Nevada, and the Klamath Mountains, where the lenticular beds sometimes attain a thickness of two thousand feet.

The Santa Lucia limestone, in the Coast Ranges, of doubtful Paleozoic age, also occur in large beds, amounting to several hundred feet in thickness, now changed to marble.

The Upper Triassic of Shasta and Plumas counties has lenses of limestone in places four or five hundred feet thick, forming important topographic features, and largely formed by the agency of corals.

The Franciscan series of the Coast Ranges has similar limestone masses of lenticular form, amounting in places to a few hundred feet in thickness, and wholly destitute of fossils, except a few traces of foraminifers.

The Cretaceous lacks limestone beds, except a local accumulation of shell limestone in the Knoxville formation of Colusa County, where a thickness of only a few feet is developed.

The Eocene of the Santa Cruz Mountains has some thin beds of limestone, and the Miocene of Santa Barbara, San Luis Obispo, and Orange counties has shell limestone amounting to as much as fifty feet in thickness. With the exception of these local occurrences there are no limestone masses in the marine beds of California from the middle of the Jurassic to the Quaternary, the Jurassic and Knoxville being characterized by thick beds of shale, and the other formations, from the Horsetown up, by enormous beds of sandstone.

Siliceous organic sediments.—Among the most remarkable features of the stratigraphy of California are the thick beds of siliceous organic sediments. In the Monterey shale of the Middle Tertiary in the Coast Ranges such sediments are extensively developed, and in places reach a thickness of five thousand feet. These are not shales in the ordinary sense, for they are chiefly organic in origin, the remains of microscopic diatoms and radiolaria. Similar deposits are known also in the Eocene of the middle Coast Ranges, but on a smaller scale. These organic siliceous shales are of great economic importance, for they have furnished nearly all of the petroleum of California.

Similar masses of siliceous organic sediments are known in the Coast Ranges in the Franciscan formation, of the earlier Mesozoic, but they are no longer shales, rather hard, flinty rocks, with the organic matter long since removed, and the fossil tests of radiolaria almost entirely destroyed, so that the rocks now show little resemblance to organic sediments.

In the Mother Lode region of the Sierra Nevada there are somewhat similar chert masses, in beds supposed to be Jurassic in age. These too are probably of radiolarian origin. In the Middle Triassic of Shasta County a series of siliceous shales almost without sand grains, and about two thousand feet thick, likewise was probably formed partly from the shells of siliceous organisms.

The Lower Carboniferous and the Devonian of Shasta and Siskiyou counties also contain many hundreds of feet of fine-grained so-called siliceous shales that are probably, at least in part, metamorphosed organic sediments. Shells of diatoms and radiolaria are extremely rare in all these older beds, but organic silica is very soluble, and even a slight degree of metamorphism destroys the delicate tests, and thus obliterates the evidence of their origin.

Coal deposits.—During the Eocene epoch plant remains accumulated to a considerable extent in the swamps of the old embayment of California, especially along the western flank of the Sierra Nevada near Ione, the Coast Range island area of the Mt. Diablo region, and in the middle Coast Ranges of Monterey, San Benito, and Fresno counties. These leaf beds have since been compacted into lignite, and in a few places into true coal.

Chemical deposits.—In Kern, San Bernardino, San Diego, and Inyo counties there are extensive chemical precipitates of salt, soda, borax, and gypsum, concentrates from the old lakes and salt pans of the arid region, from Tertiary up to the present. The areal extent is not large, but they are scattered over enormous stretches of country, and are of great present or prospective economic importance.

Comparative Rate of Formation of Calcareous and Arenaceous Sediments

Most estimates of the relative rate of formation of calcareous and arenaceous sediments are merely conjectural. A method is here suggested by which a somewhat more reliable estimate may be made. It is based on the comparative thickness of a single formation in the Californian region with that of the same formation in another region. This can be reliable only when the entire formation is represented in both regions compared, and when the conditions are reversed. We have two such cases in the Carboniferous of California and the western part of the Mississippi Valley region, and in the Cretaceous of the same regions.

The McCloud limestone of California represents nearly the whole Coal Measures, with only a small part of the upper division absent, and it is all rather pure limestone with a thickness of about two thousand feet. The Coal Measures section of Arkansas embraces all but the uppermost part of the formation, and the thickness is approximately twenty thousand feet, if we leave out the Poteau group, which is probably higher than the top of the McCloud limestone of California. This would indicate that it takes approximately ten times as long for a foot of limestone to form as it does for a foot of sandstone.

A similar conclusion may be drawn from a comparison of the Cretaceous sections of the two regions; and here the West Coast has an arenaceous section, while the Cretaceous rocks of the Southwest are in places entirely calcareous, a reversal of conditions from those of the Carboniferous.

The Cretaceous section of northern California shows a thickness of about thirty thousand feet, all sandy, and evidently deposited in shallow water in a synclinal trough, just as was the Coal Measures sandstone of Arkansas and Oklahoma. The Cretaceous beds of the Southwest, ordinary marls and chalky limestones, have, where not mixed with sandy deposits, a thickness of about three thousand feet. This again indicates that it takes about ten times as long for the accumulation of a foot of limestone to accumulate under ordinary conditions as it does for a foot of sandstone.

Of course the thicknesses vary in different parts of the same region, and at best are only rough estimates; also we cannot be sure in widely separated regions whether we have exactly the same geologic units represented in the sections compared. Also it is not at all likely that all limestones or all sandstones are laid down at even approximately the same rates. Still the agreement of the figures is too great to be accidental.

If we accept this ratio of ten to one for rates of formation of sandstone and limestone, we have a means of estimating the relative length of time consumed in laying down the rocks of the various formations, even when their lithologic character is different. Thus the Triassic of the Great Basin region, with only four thousand feet of calcareous sediments, probably represents at least one-third longer time than the Cretaceous of California, with its thirty thousand feet of sandy beds. The Tertiary formations of California, which are about fifteen thousand feet thick, represent about one-half the time of the Cretaceous, which is twice as thick, and about one-third of the time of the Triassic of this region, which is hardly one-fourth as thick. The other formations are too incompletely developed here, or too varied in composition, for any reliable estimate of their relative length of time to be made. The Carboniferous section is complete, but has sandstones, shales, limestones, and tuffs alternating in such a manner that, with our present knowledge, it is hardly possible to estimate the entire system in terms of limestone.

NEOCENE FORMATIONS OF CALIFORNIA

Because of the numerous formations that have been named in the Tertiary of California, and the numerous changes that have recently been made in the nomenclature and succession of these formations, a detailed table is here added, for the sake of those interested in West Coast geology, and not familiar with its details.

The great development of petroleum in California and the intense activity of geologists in that field are responsible for the embarrassing wealth of formational names in the Neocene. They are necessary, at present, for it is a difficult matter to correlate the minor horizons with accuracy over such a large region.

Quaternary			Faunal Zone	San Diego		Los Angeles			Ventura		
Pliocene	Upper	Merced	Zone of Scutella interlineata			Fernando formation	Upper Fernando Deadman Island beds with Pecten caurinus		Fernando formation		Fernando formation
	Lower	San Diego	Zone of Pecten healeyi	San Diego	Sandstones with Pecten healeyi and Pecten hemphilli Type section		Middle Fernando with Pecten hemphilli			Middle Fernando with Pecten healeyi	
Miocene	Upper	San Pablo	Zone of Pecten wattsi and P. coalingaensis	Carrizo formation	Sandstones with Pecten carrizoensis and P. cerrosensis						
							Lower Fernando			Lower Fernando with San Pablo fauna	
			Zone of Pecten oweni								
	Middle	Santa Margarita	Zone of Pecten estrellanus and Trophon carisaensis								
			Zone of Tamiosoma and Ostrea titan								
			Zone of Pecten discus								
		Monterey				Puente shales	Diatomaceous shales resembling the Monterey	Modelo	Modelo formation	Flinty shales resembling the Monterey	Monterey
	Lower	Vaqueros	Zone of Agasoma and Pecten andersoni			Puente sandstone	Sandstones with fauna like that of the Ocoya formation			Barren sandstones	
			Zone of Pecten magnolia and Turritella inezana			Vaqueros	Sandstones with Turritella inezana		Vaqueros	Sandstones with Turritella inezana and Mytilus mathewsoni	Vaqueros

NEOCENE SECTIONS OF CALIFORNIA

	Santa Barbara		Kern		Coalinga		San Luis Obispo		Salinas Valley		S	
	Fernando formation	Upper Fernando with Pecten bellus			Tulare	Lake beds with Pliocene fauna with some brackish-water beds	Paso Robles	Type section of Paso Robles, supposed to be of freshwater origin	Paso Robles	Gravels like those of the type section	Merced	M of ce wa Sa
do i		Middle Fernando			Etchegoin formation	Beds with Pecten wattsi and P. coalingaensis	Pismo formation ?	Doubtfully referred to this horizon. It may be the equivalent of the Santa Margarita	Etchegoin	Sandstones with Scutella gibbsi and Pecten wattsi	Purisima	I F
do na		Lower Fernando										
					Coalinga formation	Jacalitos beds with Pecten oweni						
						Beds with Tamiosoma gregaria, Ostrea titan, and Pecten estrellanus	Santa Margarita	Typical sandstones with Ostrea titan Tamiosoma gregaria, and Pecten estrellanus	Santa Margarita	Type section of Santa Margarita with Ostrea titan Tamiosoma gregaria and Pecten estrellanus	Santa Margarita	S
		Pecten discus beds						Pecten discus beds		Pecten discus beds		
e	Monterey	Diatomaceous shales, resembling the Monterey	Monterey	Bituminous shales		Doubtfully referred to the Monterey	Monterey	Diatomaceous shales, like the typical Monterey	Monterey	Type section of Monterey shale	Monterey	di
			Ocoya Creek beds	Barker's ranch beds with Agasoma barkerianum Agasoma kernianum and Pecten andersoni	Temblor	Type section of Temblor, with fauna like that of the Ocoya Creek formation	Temblor	Sandstones with Agasoma gravidum Turritella ocoyana and Mytilus mathewsoni			Temblor	S Ag Tu Pe
h na w-	Vaqueros	Sandstones with Turritella inezana and Pecten magnolia			Vaqueros		Vaqueros	Massive sandstones with Turritella inezana Pecten magnolia and Mytilus mathewsoni	Vaqueros	Type section of Vaqueros, massive sandstones of the Santa Lucia Mts. with Turritella inezana	Vaqueros	S Tu

Coalinga	San Luis Obispo		Salinas Valley		Santa Cruz			Mt. Diablo Region	
Lake beds with Pliocene fauna with some brackish-water beds	Paso Robles	Type section of Paso Robles, supposed to be of freshwater origin	Paso Robles	Gravels like those of the type section	Merced	Marine beds of Lake Merced and fresh-water beds of Santa Clara	Santa Clara	Berkeleyan	Freshwater Pliocene and Miocene of the Berkeley Hills
					Purisima	Marine beds of Half Moon Bay with Pecten healeyi			
Beds with Pecten wattsi and P. coalingaensis	Pismo formation ?	Doubtfully referred to this horizon. It may be the equivalent of the Santa Margarita	Etchegoin	Sandstones with Scutella gibbsi and Pecten wattsi					
								San Pablo	Type section on San Pablo Bay with Pecten pabloensis and Astrodapsis tumidus
Jacalitos beds with Pecten oweni	Santa Margarita	Typical sandstones with Ostrea titan Tamiosoma gregaria, and Pecten estrellanus	Santa Margarita	Type section of Santa Margarita with Ostrea titan Tamiosoma gregaria and Pecten estrellanus	Santa Margarita	Sandstones with Ostrea titan and Astrodapsis antiselli		Santa Margarita	Kirker's Pass beds with Santa Margarita fauna
Beds with Tamiosoma gregaria, Ostrea titan, and Pecten estrellanus									Sandstones with Ostrea titan and Pecten crassicardo
		Pecten discus beds		Pecten discus beds					
Doubtfully referred to the Monterey	Monterey	Diatomaceous shales, like the typical Monterey	Monterey	Type section of Monterey shale	Monterey	Bituminous diatomaceous shale		Monterey	Monterey shale
Type section of Temblor, with fauna like that of the Ocoya Creek formation	Temblor	Sandstones with Agasoma gravidum Turritella ocoyana and Mytilus mathewsoni			Temblor	Sandstones with Agasoma gravidum Turritella ocoyana and Pecten andersoni		Contra Costa	Sandstones with Agasoma and Turritella ocoyana
	Vaqueros	Massive sandstones with Turritella inezana Pecten magnolia and Mytilus mathewsoni	Vaqueros	Type section of Vaqueros, massive sandstones of the Santa Lucia Mts. with Turritella inezana	Vaqueros	Sandstones with Turritella inezana			

SYNOPSIS OF QUATERNARY HISTORY OF CALIFORNIA

<table>
<tr><td>RECENT</td><td colspan="2">Subsidence epoch of Golden Gate and other bays</td><td colspan="3">Invasion of Golden Gate River System by tide water and formation of the harbors of the West Coast. This subsidence has been going on until very recent time, for Indian shell mounds around the Bay of San Francisco are partly flooded</td></tr>
<tr><td rowspan="5">QUATERNARY</td><td>Terrace epoch</td><td>Terrace</td><td colspan="3">Period of uplift and scouring out the channels filled during the San Pedro epoch, forming terraces in the fluviatile sediments of San Benito Valley, and nearly all the valleys of the Coast Range. The youngest (lowest) terraces of the San Pedro truncate the upper San Pedro beds and are later than they. The older (higher) wave-cut terraces of the West Coast probably date back to the Sierran epoch</td></tr>
<tr><td>Upper San Pedro</td><td rowspan="2">Champlain</td><td rowspan="2">Epoch of depression along the coast
Coast stood 300–700 ft. lower than now</td><td>Warm water marine fauna</td><td rowspan="2">Epoch of filling pre-existing valleys with gravels and other fluviatile sediments. Seen in the Salinas Valley, Santa Clara Valley, San Benito Valley, and the Great Valley</td></tr>
<tr><td>Lower San Pedro</td><td>Cold water marine fauna</td></tr>
<tr><td rowspan="2">Sierran epoch. Probably longer than all the rest of the Quaternary</td><td>Glacial</td><td colspan="2" rowspan="2">Period of elevation of the West Coast, forming the great canyons off the Sierras and the submerged canyons of the coast. A period of no marine sediments (now exposed). In part contemporaneous with the Glacial epoch, for the glaciers of the Sierra Nevada came down some of the Canyons.
The West Coast then stood about 3,000 ft. higher than now, as shown by the submerged Monterey Bay Canyon at a depth of 3,000 ft.</td><td rowspan="2">The principal terracing along the coast took place at this time, and also the Channel Islands were connected with the mainland, as shown by the Santa Rosa Mammoth</td></tr>
<tr><td>Pre-Glacial</td></tr>
<tr><td>PLIOCENE</td><td>Merced Beds</td><td></td><td colspan="3">Period of depression and filling of troughs with marine Pliocene sediments, and formation of great Pliocene lakes above sea-level</td></tr>
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